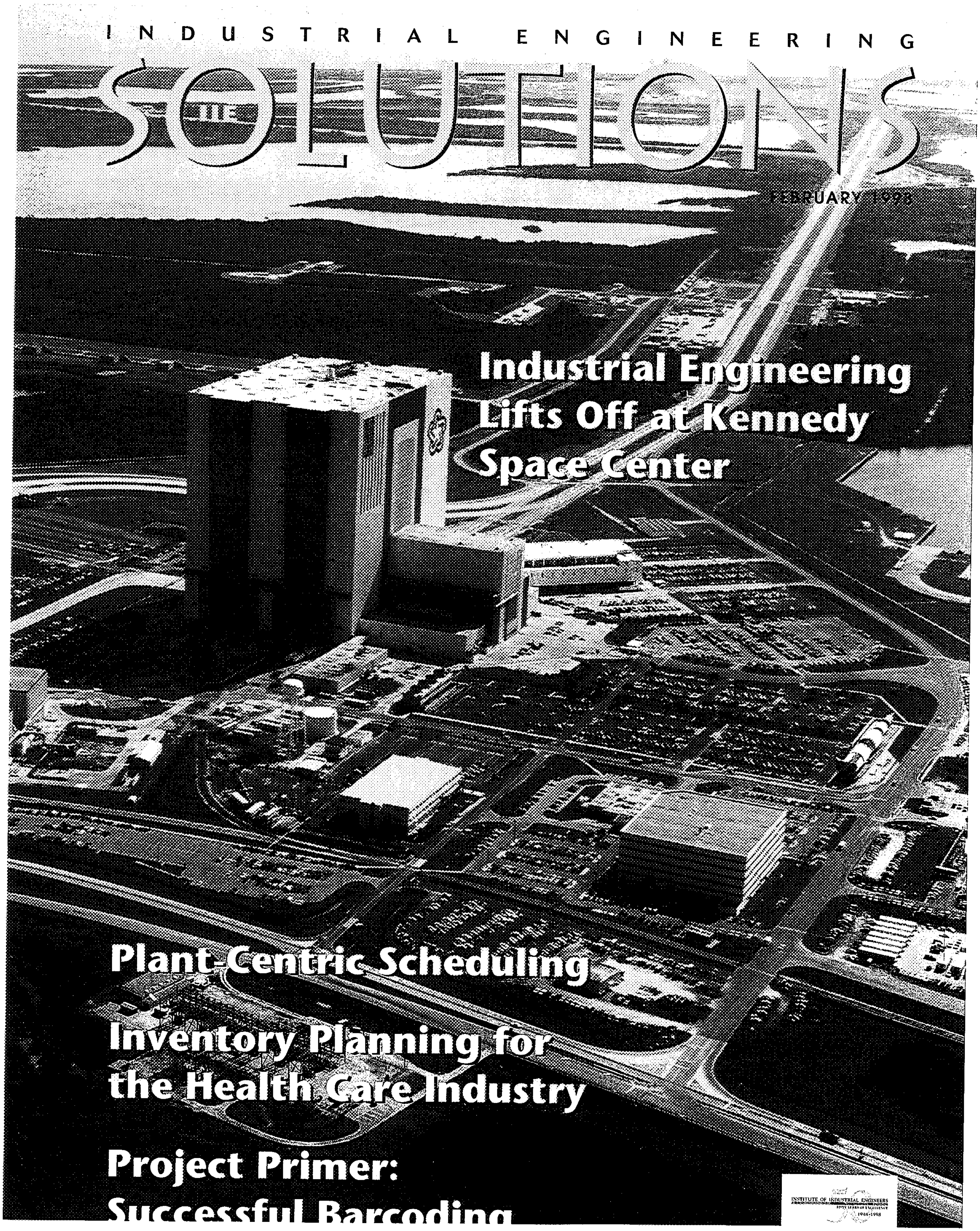
INDUSTRIAL ENGINEERING
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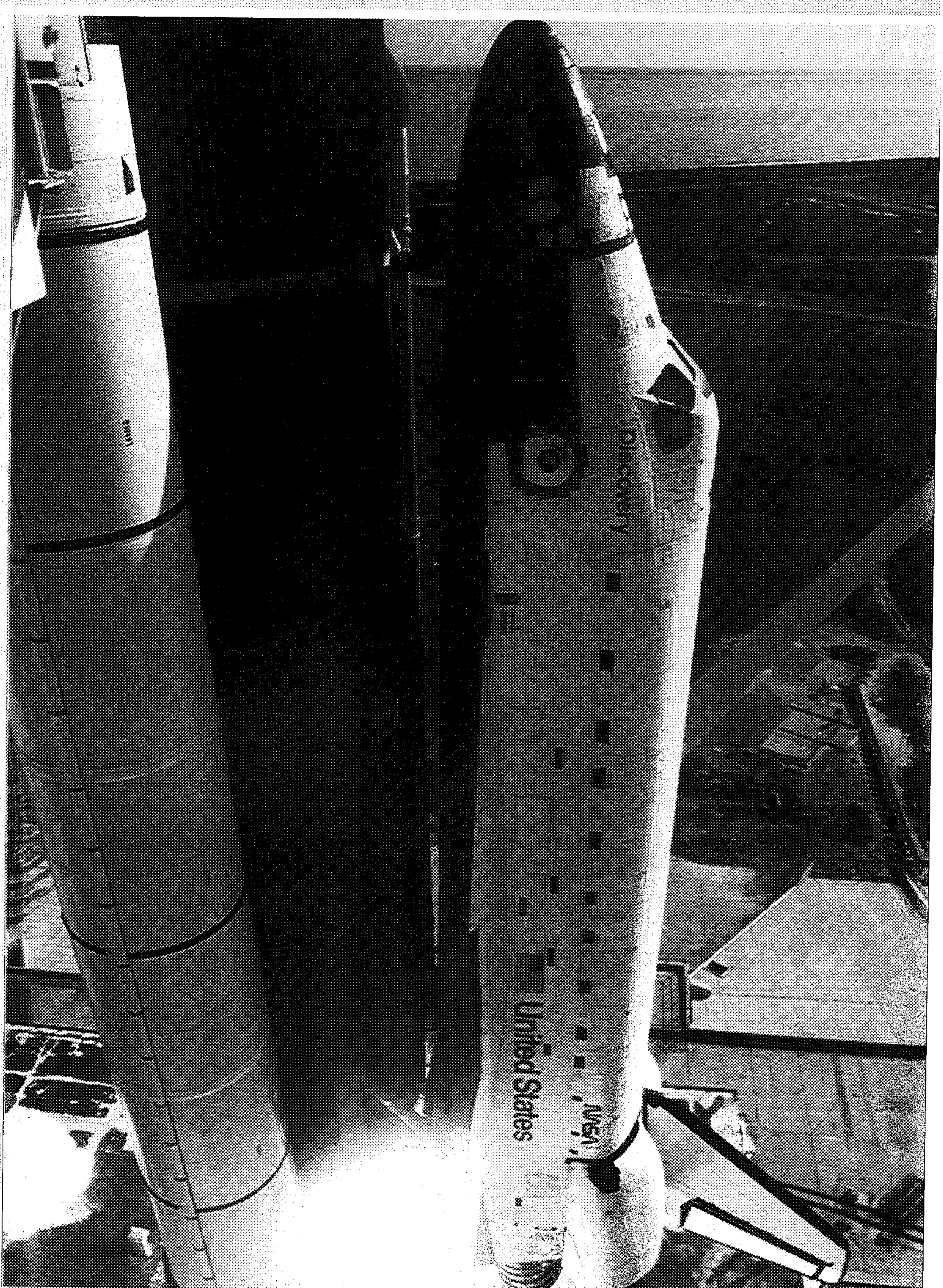
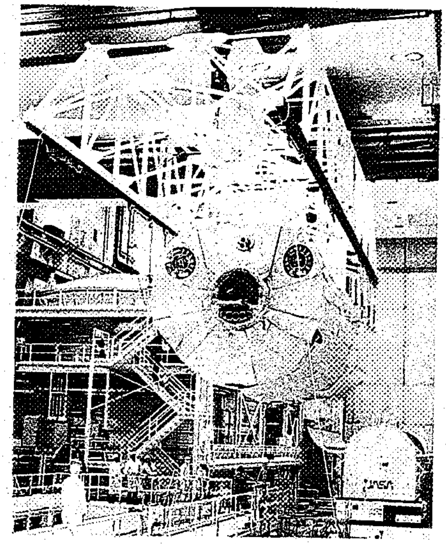
IIE
FEBRUARY 1998
Industrial Engineering Lifts Off at Kennedy Space Center
Plant-Centric Scheduling
Inventory Planning for the Health Care Industry
Project Primer: Successful Barcoding
INSTITUTE OF INDUSTRIAL ENGINEERS
1948-1998


Discovery
United States
NASA

With thousands of components that must operate in perfect unison during launch and orbit, the space shuttle is one of the most complex machines ever built. After more than 15 years of shuttle missions, human space flight remains a risky business. Similarly, the KSC processes for preparing and launching missions into earth orbit and beyond are among the most complex and risky in the world. The KSC team deals with this complexity and risk on a daily basis. KSC tasks are labor intensive, require a high level of teamwork, and have little or no margin for error.

Orbiter processing illustrates the magnitude of the KSC challenge. The preparation of an orbiter in its "hangar," the orbiter processing facility, requires scheduling more than 1,500 tasks with nearly 20,000 constraints. When three orbiters are processed simultaneously, which is usually the case, more than 4,500 tasks and 60,000 constraints are orchestrated and frequently adjusted due to the unplanned work that results from the complexity of the hardware. In addition, many tasks are hazardous operations involving toxic substances and explosive materials.



Payload preparations in the Operations and Checkout Building

Although the spacecraft hardware is unique, the *processes* used to accomplish KSC's mission are similar to processes used in many industrial environments. Examples of core business processes are preparing work instructions, planning and scheduling tasks, providing parts and support services, and executing tasks on the shop floor. Like many operational environments, KSC is rapidly changing due to budget cuts, privatization of daily shuttle operations, attrition, process reengineering, process enhancements, and new shuttle system upgrades. KSC is facing the generic problem of "doing more with less," and IE capabilities and technologies are providing some of the solutions.

Development and implementation of IE

In 1989, KSC was still recovering from the *Challenger* tragedy of 1986. The agency's primary emphasis was (and still is) on flight safety. Although NASA hired several IEs over the years, an IE department and clear IE career paths did not exist. Therefore, most NASA IEs quickly assumed different functions and responsibilities. Since shuttle test and checkout activities involved the most labor intensive, costly, and repetitive tasks at KSC, NASA's Shuttle Processing organization was a good place to initially test and demonstrate the applicability of basic IE principles and techniques.

Senior NASA managers had the foresight and vision to see that proactive steps were needed to ensure an efficient and effective shuttle program for many years to come. In 1989 most efforts at reducing cost and cycle time were focused on the orbiter's thermal protection system (TPS), which includes more than 20,000 delicate ceramic tiles. The tiles must be inspected and repaired as necessary between flights. TPS processing was clearly on the critical path and consumed more than half the total labor hours required between flights. Consistent with NASA's culture, advanced hardware (i.e., robots) and software (i.e., artificial intelligence) were often looked upon to provide many of the solutions for processing bottlenecks. Ad hoc, or "Tiger," teams also made significant progress in other areas, but those teams rarely included industrial engineers.

TPS processing activities provided an excellent testbed for IE techniques and methodologies. A small industrial engineering initiative began investigating a variety of process improvement strategies in TPS processing—more than just strategies involving advanced technologies. A common approach to process improvement was to develop an advanced hardware/software technology solution and then look for operational problems to fix (a "technology push" approach), rather than identifying a process improvement need and then examining all alternatives for closing the performance gap, including advanced technologies (a "technology pull" approach). The TPS IE initiative soon demonstrated that relatively simple, common-sense, easy-to-implement process changes often delivered outstanding returns on relatively small investments of time and equipment. NASA management recognized the potential of a formal IE function with a larger

Core IE Capabilities	Examples
Process analysis and modeling	Process simulation process control, root-cause analysis, process reengineering
Management support systems	Metrics, performance measurement systems, decision modeling, risk analysis, cost-benefit analysis
Human factors engineering	Ergonomics, team dynamics, human error investigation/root-cause analysis
Work measurement/ methods engineering	Work methods analysis, task standards, associated measurement systems
Planning and scheduling systems	Scheduling techniques, schedule risk assessment, resource loading/leveling
Quality management	Facilitation, coaching, and support of cross-functional continuous improvement and benchmarking teams

Table 1. IE capabilities for shuttle processing

Industrial Engineering Lifts Off at Kennedy Space Center

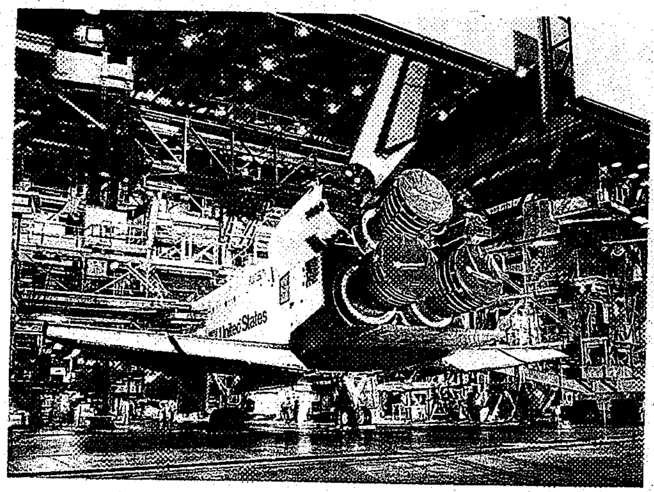
BY TIM BARTH

When the National Aeronautics and Space Administration (NASA) began the Space Shuttle Program, it did not have an established industrial engineering (IE) capability for several probable reasons. For example, it was easy for some managers to dismiss IE principles as being inapplicable at NASA's John F. Kennedy Space Center (KSC). When NASA was formed by the National Aeronautics and Space Act of 1958, most industrial engineers worked in more traditional factory environments. The primary emphasis early in the shuttle program, and during previous human space flight programs such as Mercury and Apollo, was on technical accomplishments.

Industrial engineering is sometimes difficult to explain in NASA's highly technical culture. IE is different in many ways from other engineering disciplines because it is devoted to *process* management and improvement, rather than *product* design. Images of clipboards and stopwatches still come to the minds of many people when the term *industrial engineering* is mentioned. The discipline of IE has only recently begun to gain acceptance and understanding in NASA. From an IE perspective today, the facilities used for flight hardware processing at KSC are NASA's premier factories. The products of these factories are among the most spectacular in the world: safe and successful launches of shuttles and expendable vehicles that carry tremendous payloads into space.

KSC overview

Each NASA center has an assigned mission and "center of excellence," or technical area of preeminence. KSC's mission is space launch, and its center of excellence is launch and payload processing systems. KSC is also NASA's lead center for expendable launch vehicles. The major space shuttle components are the orbiter, the external tank, and the solid rocket boosters. Payloads include any items launched into space by the reusable space shuttle or expendable vehicles. The KSC team is responsible for the preparation, launch, and landing of the orbiters, crews, and payloads as well as the recovery of the solid rocket boosters.



Orbiter roll-in to hangar in the Orbiter Processing Facility

scope, and a small processing enhancement task team—consisting of an astronaut between missions and two engineers—was chartered.

Over the next two years, the task team developed the initial strategies for a formal NASA industrial engineering function. The major focus was supporting the design and development of an integrated work control system, which included subsystems for capacity resource planning, work instruction generation, requirements tracking, and shop floor data collection. The shop floor data collection subsystem was designed to support a comprehensive, systematic methodology for identifying process improvement opportunities, analyzing root causes of process problems, and evaluating enhancement alternatives.

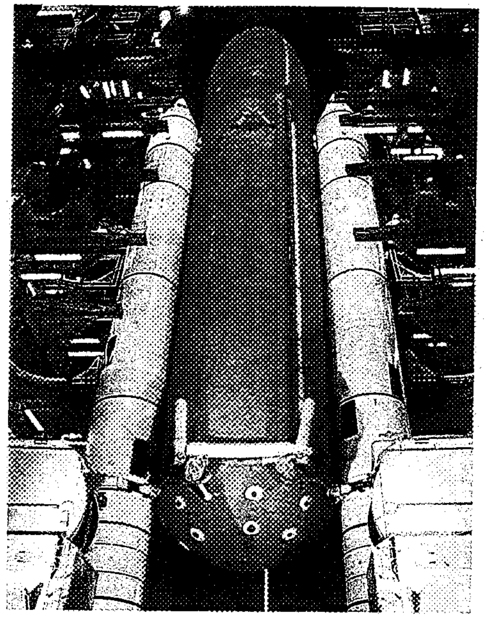
Based on the success and recommendations of the processing enhancement task team, a formal NASA IE office was established in 1992. Through a partnership with a local university, specific capabilities to address the IE needs identified by the task team were developed. The initial capabilities included simulation, work measurement, methods engineering, and benchmarking. Additional capabilities continue to evolve and mature in response to customer needs and expectations. Current shuttle processing IE capabilities are summarized in Table 1.

The Shuttle Processing IE Team reached a milestone for implementing its capabilities when it adopted an "internal consulting" approach for process analysis and improvement. Under this approach, the team recognized that its role was to *influence* change through recommendations developed by application of its unique capabilities and perspectives, and through support of cross-functional improvement teams. Projects were formulated with partners from other contractor and NASA organizations. As the projects went through concept, design, development, and implementation phases to operations and maintenance, the role of the IE "consultant" generally diminished.

IE solutions at KSC

The entire Shuttle Processing Team has made tremendous improvements over the past decade. Significant reductions have been achieved in the cost per shuttle flight (including a reduction in labor hours and overtime) and the number of processing incidents. During 1997, the team launched all eight missions on time, with six launches within a minute of the start of the launch window.

The Shuttle Processing IE Team works with NASA and contractor partners to develop and implement process improvements, and to enhance the quality of the work environment. The process improvements address all key objectives identified by the Clinton Administration's National Performance Review—to improve customer service, eliminate unnecessary spending, cut red tape, and empower employees. They also address NASA's top priority—safety. The National Performance Review is trying to establish "common sense government." Since industrial engineering is sometimes called a "common sense engineering discipline," IEs are well equipped to generate solutions in new government systems and processes. Accomplishments of the Shuttle Processing IE Team and its partners include the following:



External tank attached to completed solid rocket booster stacks.

• *Improved customer service*—The NASA IE team worked with the space flight operations contractor to implement the shop floor data collection system described above. The system measures the satisfaction of front-line employees performing work on the shop floor. Before the system was established, the customers were not clearly identified and shop floor customer satisfaction was not routinely evaluated. Technicians now enter data on the timeliness and quality of the products and services they receive each day in all major shuttle processing facilities.

A cross-functional process analysis team analyzed root causes of selected delay types and prepared recommendations for proactive process improvements. Customer feedback from technician surveys was used to develop a computer-based training initiative that resulted in training modules available in the shop areas on demand. One module trained technicians on the need for data consistency and the benefits of providing the customer feedback data in the shop floor data collection system.

Impact: The contractor reports a reduction in the processing task delay rate due to the improved focus on shop floor customer service, and a reduction in recertification training costs.

• *Elimination of unnecessary spending* —A discrete-event simulation model of the process for quantifying orbiter spare part requirements was developed with partners in the KSC logistics organization. The model emulates the "spares" process and allows a cost-effective comparison of alternatives. The model was applied to orbiter auxiliary power units, and the analysis produced the information necessary to reverse an external recommendation to upgrade additional units

Impact: A cost avoidance of up to $14.7 million was realized by the shuttle program. An additional model is being developed to assist in decision making for other orbiter spares, such as fuel cells.

• *Improved safety*—One of KSC's primary goals is "safety and health first." By supporting the Shuttle Processing Human Factors Team, IEs successfully applied two years of collaborative work with NASA's Ames Research Center, the Center for Creative Leadership, and the U.S. Air Force Academy to develop an innovative incident investigation tool. The tool, which is called the "KSC human factors event evaluation model," assists investigators in looking at the "big picture" and analyzing the often invisible processes of teaming, leadership, group behavior, interpersonal behavior, and organizational practices.

Impact: Before the event evaluation model was implemented, the cause of an incident was frequently listed simply as "human error." Additional steps are now taken to understand the contributing causes of human errors so effective actions can be taken to prevent them from recurring. Trend data have been analyzed to enable a more systematic, proactive approach to improving workplace safety. Ames Research Center and KSC have cohosted human factor workshops for commercial airline maintenance centers to transfer technologies and lessons learned.

• *Empowered employees*—Since its inception, the NASA Shuttle Processing IE Team has relied on empowered employees. Productive partnerships with local contractors, other NASA organizations, small businesses, and universities assisted the team in establishing and refining its capabilities.

Impact: IEs have provided valuable services to KSC and to additional NASA centers, such as Stennis Space Center and Marshall Space Flight Center. IEs are capable of providing value-added services to meet additional NASA and government needs. A group of self-directed KSC IEs has recently established a centerwide team called the "KSC IE network," which directly supports KSC's goal to "build reliance and teamwork everywhere." The IE network has initiated efforts to improve the exchange of technical information and practical experiences, refresh and expand IE skills, improve IE understanding and awareness, and develop common IE processes and metrics.

• *Additional results*—The work of the shuttle processing IE team has been recognized externally through the President's Quality Award Program, which is the federal government's version of the Baldrige Award. KSC received a Quality Improvement Prototype Award in 1995 and a Special Quality Achievement Award in 1996. The IE team was also a partner in the development and implementation of six KSC "best practices" recognized by the Best Manufacturing Practices Center of Excellence.

Future directions: Earth, Moon, Mars, and beyond

KSC IEs plan to continue their involvement in a number of activities, including support of the shuttle program, new human space flight programs, and additional initiatives. The following plans are, of course, subject to change as the NASA journey continues.

• *Shuttle program*—The space shuttle is currently scheduled to fly beyond the year 2012. Any plans require a safe, successful shuttle program. As daily operations are transitioned to the space flight operations contractor (the United Space Alliance) and as the fleet ages, NASA must rely more heavily on data and metrics to support decision making. Certification of flight readiness, contractor evaluations, and transition and enhancement/ upgrade decisions will be metric-based.

Star birth in the Eagle Nebula as revealed by NASA's Hubble Space Telescope

IEs will have a key role in the process analysis function required to transform operations data into meaningful information supporting these decisions. Major system upgrades are integral components of NASA's efforts to ensure a safe, reliable, and affordable shuttle program. IE capabilities may be used to evaluate proposed upgrade projects and to ensure a systems approach to upgrade implementation. When hardware and software systems are upgraded, an overall systems approach (which considers the hardware, software, workers, processes, and work environment) is required to maximize the return on investment.

• *New human space flight programs*—New human space flight programs are managed under a strategic NASA enterprise called "Human Exploration and Development of Space." Industrial engineering is frequently used to optimize the operational phase of a program. To enhance overall performance and quality in many programs, it is necessary to continually improve and reengineer the processes of how work is done. The space shuttle is NASA's first major program with a long-term operational phase, and many current and potential future programs (e.g., the International Space Station, X-vehicles, and human space flight to Mars) also are projected to have lengthy operational phases. Therefore, IE technologies and capabilities are becoming even more strategically important to NASA.

• *Additional initiatives*—KSC IEs will continue to contribute to NASA process improvements, which will be fostered by ISO 9001 documentation requirements for core NASA processes. IEs will also provide services, as requested, to additional NASA centers, strategic NASA enterprises (such as continued collaboration with aircraft maintenance centers), and government agencies. Consistent with NASA's role as a world-class research and technology development organization, KSC IEs will also develop valuable new IE technologies.

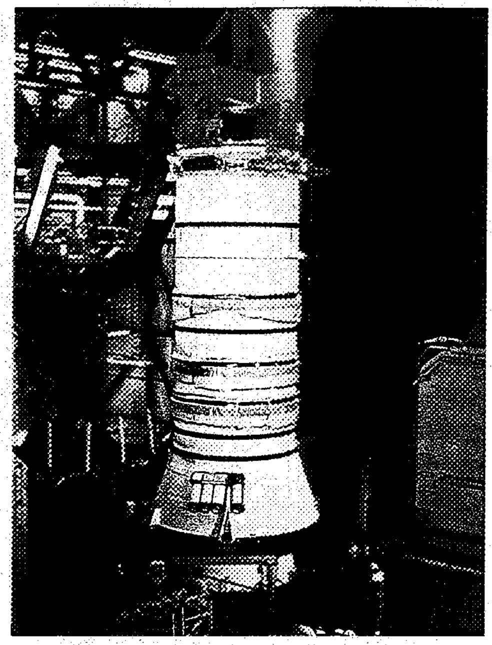
IE technology development

Most IE technologies evolved from the need to improve shop floor productivity to remain competitive in the marketplace. IE technologies are now being successfully applied to every type of process in government agencies, production industries, service industries, and academia. The growing need to do things "better, faster, and cheaper" throughout government and industry has increased the demand for IE technologies and capabilities at KSC and other organizations. Research and development efforts in the technologies associated with industrial engineering are aligned with NASA's mission statement: "NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on earth."

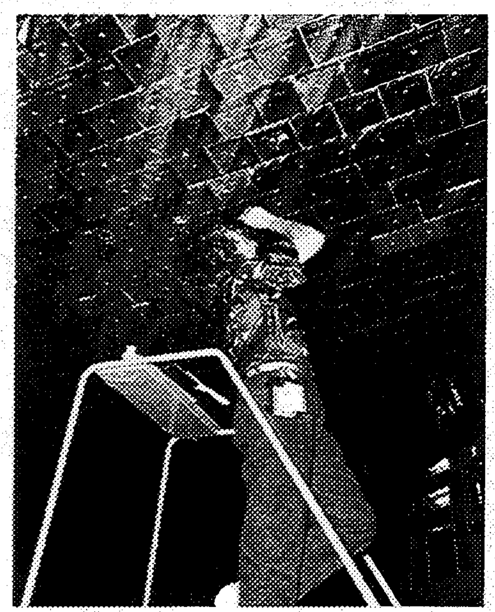
As the industrial engineering discipline is further established within NASA and its contractors, KSC plans to perform additional development of IE technology. After IE technologies are developed, existing technology transfer mechanisms, including technology transfer and space act agreements, can be used to disseminate applied research results to a wide variety of American industries.

KSC IEs are also involved in the Small Business Innovation Research (SBIR) program, a congressionally mandated program that provides seed capital to help American-owned small businesses participate in federal research and development efforts. For example, one SBIR project, titled the "Schedule/Cost Risk Analysis and Management System," expanded the state-of-the-art in project management tools by developing algorithms for explicitly modeling specific risk factors and for new measures of resource-constrained task criticality. The conceptual framework for these advances had been discovered in an article published shortly after the program evaluation and review technique (PERT) was developed in the 1950s, but the concepts were not pursued or implemented until the NASA SBIR project was funded in 1993.

Since KSC has several operational "factories" with unique characteristics, it is an ideal testbed for IE and IE-related technologies. For example, an expert system-based scheduling tool called the "ground processing scheduling system" was successfully developed in an operational testbed environment with the space flight operations contractor and NASA's Ames Research Center. KSC plans to provide expanded technology testbed services in the near future.



Solid rocket booster stacking in the Vehicle Assembly Building



Tile inspections under the Orbiter

Conclusions

A marketing phrase is "perception may not be reality, but reality is perception." One indicator of the progress of NASA's IE capabilities is changing perceptions. In 1989, industrial engineering was commonly perceived as a *luxury* at KSC. In 1998, it is commonly perceived as a *necessity*. Of course, IEs in all organizations must continue to deliver outstanding recommendations and services to earn additional credibility and customers. Like most other service organizations, they must satisfy customer needs "anytime and anywhere." IEs have the potential to play a major role in the future of NASA and additional government agencies. In the era of government reinvention, NASA will need to fund new programs by cutting the operational costs of current programs and by optimizing the operational costs of new programs during their concept, design, and development phases. Therefore, the opportunities for IE contributions at NASA are truly astronomical. IE

For further reading

Murray, Susan L., Amanda M. Mitskevich, and Robert R. Safford, "Work Measurement at Kennedy Space Center," *IIE Solutions*, July 1995.

NASA 1998 Strategic Plan. NASA Policy Directive (NPD)-1000.1.

Tim Barth is a member of the KSC Shuttle Processing IE Team. He has a bachelor's degree in mechanical engineering from the University of Nebraska, a master's in aerospace engineering from the University of Arizona, and will soon receive a master's in operations research from the University of Central Florida. Additional members of the KSC IE Network, Shuttle Processing Human Factors Team, KSC Benchmarking Clearinghouse, Technology Testbed Team, and KSC Trade Show Design Team contributed to this article.

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